Denmark. Dan. Fish. Mar.
(1) Kgl. Dan. Vidensk. Selsk. Skrifter. Naturvidensk. og Mathem. Afd. Serie: Hydrogr.

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SERIE: HYDROGRAFI · BIND 1

Nr. 11. J. N. Nielsen: CONTRIBUTION TO THE UNDERSTANDING OF THE CURRENTS IN THE NORTHERN PART OF THE ATLANTIC OCEAN. WITH 1 PLATE

KØBENHAVN
I KOMMISSION HOS C. A. RIETZEL
BIANCO LUNOS BOGTRYKKERI
1908

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CONTRIBUTION

TO

THE UNDERSTANDING OF THE CURRENTS IN THE NORTHERN PART OF THE ATLANTIC OCEAN

BY

J. N. NIELSEN

WITH 1 PLATE

KØBENHAVN
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As the conclusions concerning the currents in the Northern part of the Atlantic, which might be drawn from the Danish hydrographical investigations of the waters surrounding Iceland in 1903—1904, were not at all in accordance with the general view of this matter, I expressed a wish to the leader of the Danish hydrographical researches, Docent MARTIN KNUDSEN, that some current-bottles should be thrown out south and east of Iceland, and this proposal was kindly agreed to.

The Central Laboratory of the international co-operation for the study of the sea in Christiania had just at that time been engaged in experiments how to produce a practical current-bottle, and of the constructed type 80 pieces were procured. This type was something between the formerly used current-bottles consisting sometimes of very strong boxes containing a bottle with label, sometimes of a bottle only, without any protection whatever. In case where the specific gravity of the box is slight enough to exclude all risk that the box in sucking water should become heavy enough to sink, this first proceeding affords almost complete safety that the box with contents will drift ashore sooner or later. As an example may be stated that 75 % of the floats of this type thrown out by the Danish Ingolf Expedition were recovered.[1]) If unprotected bottles are employed a number of these will invariably break, for instance in high sea when drifting along a rocky shore, still it appears that we may also here reckon that a rather large percentage will be found. This may for instance be seen from the fact that of 785 bottles[2]) thrown out by the Danish Meteorological Institute in 1899—1901, 225 or 29 % were drifted ashore (in 1905 probably[3])). If we moreover take into consideration that the main part have reached thinly populated coasts, the result must be said to be very satisfactory.

The 80 bottles supplied by the Central Laboratory were partly protected. They had been dipped into thick pitch, and had acquired a layer of this, which again had been covered with canvas. This proceeding had several advantages. In the first instance the bottle may better resist shocks being protected by the pitch, and this is by the canvas prevented from breaking in small pieces by such shocks. Of far greater importance it is, however, that the layer of pitch and canvas, which surround the bottle, is made in such a way that the specific gravity of the whole vessel approaches 1 very closely, why it will be drifting in the surface with only a very small part above it, for which reason it will be bound to follow the movements of the surface water to a far higher degree than the case would be if a greater part of the bottle rose above the water. In that case it would be exposed to the wind's direct influence, and thus it might very well be supposed to move into a direction deviating from that of the surface water.

Each bottle contained a label of thick paper on which was printed the number of the bottle and a request in the Danish and English language to forward the label to the hydrographical laboratory of Copenhagen, adding place and time when the bottle had been found, for which trouble a postal order of 2 Kroner was offered. I thought it necessary to make this arrangement in order to obtain the labels, having had occasion to make sure that we are far from receiving all the labels of the great number of

[1]) C. F. WANDEL: Current-bottles. The Danish Ingolf Expedition. Vol. I, 2. Copenhagen 1899.

[2]) C. RYDER: Some investigations relating to the ocean currents in the sea between Norway, Scotland and Greenland Naut. Met. Annual of the Danish Meteorological Institute 1901. Continuation 1904.

[3]) The paper was printed in 1905, but a date is not given for the closure of the list of recoveries.

current-bottles, which have been thrown out by the different countries, without promising a reward to the finder. However, many people take a happy interest in the floating of such bottles, what may be seen from the fact that many of the finders ask for an explanation as to where and when the bottles were thrown out. The main advantage of the bottles employed is, as mentioned above, that the specific gravity is so nearly equal to that of the water, that the influence of the wind will be quite inconsiderable, and the protection by pitch and canvas is at the same time easy and cheap. On the durability of this proceeding I am unable to give my opinion having had no opportunity of examining any of the landed bottles, but one of the finders, TÖLLÖF KRISTOFFERSEN, has supplied the label N° 22 with the following communication: "In walking along the beach I discovered a bottle covered with pitch all over, the cork excepted. On opening it I found the enclosed label; whether this is of any value may be uncertain. I send it however all the same". This indicates that the pitch is quite durable, even if the bottle may be laying rolling at the beach, the canvas being not mentioned, it has probably been worn off. How far protected or unprotected bottles should be used (if the bottles are not thrown into or passing through an icy water) depends upon the use we intend to make of them. Thus if we want only to obtain information concerning the rapidity of the current, protected bottles may be regarded as a doubtful advantage, as these with far greater probability may drift ashore and remain there for some time and afterwards may be carried off by high tide, again to land somewhere else, and so on. Thus it may have stayed ashore for years in different places without being found, and in this way the value it may indicate with regard to the rapidity of the current becomes perfectly worthless. An unprotected bottle will in all probability not be "old", as it sooner or later will be sure to break when knocked against rocks or stones on the beach.

Before we commence to treat the drifting of the current-bottles in question we shall in general mention the results which may be drawn from the drift of such a bottle. The view is still sometimes held, that if a bottle thrown out somewhere in the sea does land on a coast, this must be ascribed to the fact that the very waters into which the bottle was thrown out meanwhile has moved from its original place and is now watering this very coast. Nothing can be more wrong, however. If we imagine for instance that a bottle has been thrown out into the Denmark Strait west of Iceland, the approximately warm and saline vater of the Irminger Stream may possibly carry it north of Iceland. As the eastern branch of the Irminger Stream here will meet Arctic water of low salinity and of less specific gravity the Irminger Stream becomes bottom-going, while the bottle will continue its course with the Arctic water. If the bottle does not land now at North Iceland, it will in all probability east of Iceland be carried southward or into south-eastern direction by the East-Icelandic polar current. As the surface water of this current however, especially in summer, shows a tendency of spreading over the Atlantic water in southern direction across the Iceland-Faroe ridge as a thin layer, which gradually will become mixed up with the Atlantic water, the possibility is not excluded that the bottle in this way may return into Atlantic water of the same qualities as that into which it was thrown, and land e. g. on the Faroe Islands. Though the water in which the bottle stayed when drifting ashore has the same physical and chemical qualities as that into which it was thrown out, it is, however, not the same, as the Atlantic water into which it was thrown, now appear in a somewhat mixed and cooled state as bottom water in the Norwegian Sea.

As several different current systems do exist in the northern part of the Atlantic, such a bottle may very well pass from one system into another, and it will always do so when carried off in a current of heavier water that meets another current of lighter water, as the water of the former will always be covered by that of the the latter, and the bottle will consequently raise in the surface of that. But even if a float is carried off in a way which make it continually remain in the same current, its movements are far from being so simple as they are often represented to be. The fact is that a current in the sea cannot be compared with a movement in a tube system: The course that is normal to the water particles may be object to many changes; heavy gales may for instance bend them

to the sides or even cause a retreating movement. We have a priori no reason to doubt this, and it appears for instance from Dr Wemyss Fulton's work on the currents of the North Sea.[1])

While the rather considerable material of current-bottles show, on the whole, a southward current along the east coast of Scotland bending towards the east around the Dogger Bank (c. 54° N. Lat.), we find an exception from this rule in December 1896 and in January 1897, as some bottles thrown into the normally east-going current drifted towards the west on account of prevailing eastern wind and landed on the Norfolk and Northumberland shores. A current is also dependent on the surrounding waters and may in this way become dependent on winds which perhaps have not blown over the current itself but nevertheless have been able to change its course perfectly. The current in the Great Belt is thus for instance in general northgoing, but when a western gale is blowing over the northern part of the North Sea it will push part of the North Sea's water into the Skagerrak and in this way produce a difference of level of the northern part of the Kattegat and the Baltic, and this difference will in the Great Belt cause a southgoing current the force of which may be several miles per hour.

It is a well known fact that considerable volumes of Atlantic water are flowing into the Norwegian Sea through the Faroe-Shetland channel. In this channel we generally find a layer of higher salinity (35·30—35·40 ‰) which like a tongue is stretching into north-eastern direction from the saline water west of Scotland, and which plainly shows that the movement of these waters takes a north-eastern direction. It is, however, not allowable from this to conclude that the current would be unable to carry a body from the Shetlands to the Faroe Isles or vice versa. A north-western gale will partly make the surface water take a more easterly direction and partly force the waters of the East-Icelandic polar current against the Atlantic current and thus displace it toward east. A south-eastern gale will have the reverse effect but having less water to influence east of the current, the secondary effects — it is the displacement caused by the pressure from the adjoining waters — will hardly become as considerable. This in connection with the fact that south-eastern gales are neither as frequent nor as long-lasting as the western ones may surely be the reason why we have no examples of driftings from the Shetlands to the Faroe Isles as in the opposite direction.

From the remarks above it will be seen that we may not judge the route of a bottle from the dates with which it is provided. These dates are besides reduced to indicate the time and place where the bottle was thrown out together with the finding place, as the time when it was found may differ very much from the time when it landed. It may e. g. have remained for a long time ashore somewhere else and again have gone to sea by high tide. On the base of these dates we may draw a route as the most probable, but we obtain no information with regard to the oscillations to both sides of this or to the possibly retrogressive movements. How interesting such information might be in many respects, many questions arise however for the solution of which they are without any importance. If we for instance make a calculation of the volume of the waters streaming through a certain section it is only the average value of the rapidity's composant perpendicularly to the section that is of any importance, while the movement in the direction of the section may be left out of consideration. Moreover it should be remembered that such oscillations in the usual direction of movement often exist only in a thin surface layer, consequently they do in many respects play no greater rôle in comparison with the lower layers in the same current as the thickness of these often may come up to several hundred meters.

Another important consideration which should be taken when the drifting of a bottle is made object to discussion is, that we cannot feel sure that several bottles thrown out at the same place should follow exactly the same route. Such a common route

[1]) T. Wemyss Fulton: The Currents of the North Sea and their Relation to Fisheries. 15th Annual Rep. of the Fishery Board of Scotland. Part III p. 334 ff. Edinburgh 1897.

might look rather natural, and several authors do also commit the error to assume it. Even if the sea was calm I perceived, however, that when several bottles were thrown out in the same place, they became soon separated considerably from each other. In "Die Fortschritte der Ozeanographie 1891 und 1892" Professor O. KRÜMMEL mentions a drifting in opposite direction of the two parts of a wooden-ship ("Fred. B. Taylor") which was run down and cut into two pieces on June 22, 1892 at 40° 19′ N. Lat., 68° 33′ W. Long. In the course of $1\frac{1}{2}$ months the hind part stranded at $43\frac{1}{2}$° N. Lat. having drifted northwards, while the other part of the wreck drifted in S. W. direction and after 3 months was observed at 37° N. Lat. In the same place Professor KRÜMMEL complains with every reason that the following experiments by Professor HENSEN[1]) were not sufficiently noticed. Professor HENSEN employed ten silvered glass-balls filled with lead to such a degree that they could just keep floating in water; these balls he threw out during rough weather ("bei sehr bewegter See") in the middle of the Kieler Bay and observed that they after 24 hours had moved so far from each other that the interval between the two outside ones was 4 miles. That it is not the wind and waves alone which make such floats move from each other I have myself had opportunity to be convinced of, having seen some bottles thrown out in calm, which also after a short time became considerably removed from each other. That the effect in this case should be ascribed to swell might seem probable. We perceive, however, that when bottles thrown out in the same place thus may separate from each other, a possibility remains that some of them may be carried off by one current while others after some time may pass into another and later on may be carried in quite another direction. But even if all the bottles continue to keep in the same current system, oscillations, which may possibly occur in the movement of the waters, may provide ample possibility for errors. If for instance a row of bottles are thrown out with short intervals on the route Faroe—Iceland, and one bottle thrown out at 12° W. Long. is found on Iceland, while one from 10° W. Long. is found on the Faroe Isles, and we from these facts conclude that the current divides between these two points, I think we are a little overhasty, as far as we have no proof that the bottle landed at the Faroe Isles has not beforehand been near the coast of Iceland, or as far as we are not guarded against the possibility that another bottle thrown out at the same time at 12° W. Long. might possibly drift ashore on the Faroe Isles. As I foresaw that this last mentioned possibility might not be excluded, I did not throw out 1 but up to 10 bottles at the same place, and as it will be seen later on, the case seems also to have occurred that two bottles from the same place have moved in opposite directions.

From the dates where a bottle has been thrown out and where it has been found we may, as formerly mentioned, construct a curve which the bottle with the greatest probability has followed. How great the deviations have been, may generally not be stated, however. From the time when the bottle has been thrown out and when it has been found (if we take it for granted that it has followed the constructed curve) we may calculate the average speed per 24 hours in the passed time, but it is evident that this way of calculation gives only a lower limit for this average speed, as we do not know for how long the bottle may have been laying ashore before it was found. This does not indicate, however, that this average rapidity of the bottle always puts a lower limit to the average value of the current rapidity according to this curve. When a larger part of the bottle rise above the water, it may be carried off by the wind with a rapidity surpassing that of the surface water, thus the average speed of this may very well be less than the average speed of the bottle in case where the bottle has been found shortly after its drifting ashore. If the specific gravity of the float is in close accordance with that of the water, as in this present case, this difference will hardly be considerable, even if the bottle is found immediately, and thus we will regard the average speed of a bottle as a lower limit for the speed of the current.

[1]) V. HENSEN: Über die Bestimmung des Planktons. V. Bericht des Kieler Komm. zur Unters. der deutschen Meere. Kiel 1891. S. 2.

Concerning the construction of the probable route of a current-bottle and in connection with this the direction of the current in a certain water, this matter becomes indeed considerably complicated, when for instance 2 bottles are thrown out between Iceland and the Faroe Isles at the same time and the one lands on Iceland and the other on the Faroe Isles — and what should be noticed — in short time enough to exclude the possibility that the latter might have been carried around Iceland by the so-called Icelandic coast current before landing on the Faroe Isles. Concerning this I shall remark that if we have to deal with a larger number of bottles the direction into which the main part of the bottles have moved should be indicated as the current direction. That some bottles so to speak take their own course is not more than might be expected.

The present table over the recovered bottles (p. 8) state the number of the bottle, the place and date when the bottle was thrown out, and also date and year when recovered, together with the finding place and the central position of this, as far as I have been able to determine it by means of different sea- and land-charts. The stated latitude and longitude will generally not deviate 10 parallel-minutes from the real finding place, and only in very few cases, for instance No. 21, where Laxefjord is named as finding place, the deviation may be somewhat greater. In this and in similar cases where the bottle has passed over a considerable distance this uncertainty does not play any rôle, as the uncertainty in the distance, which it causes, only amounts to a few per cents. I have only in a few cases been obliged to make inquiries in order to obtain further information from the finder. On a chart of the same size as the accompanying one (scale 1 : 9000000) I have drawn the probable routes for the bottles, and the length of the forthcoming curves has been measured by means of a curvimeter whose hand moved one division of about 1 mm.'s length for a movement of 1 cm. along the curve, the length of this may thus be supposed to be measured with an exactness of 1 mm. what a repetition of all the measurements also suggests, but even if we suppose a mistake of 2 mm. to have taken place in the measurement of the length of the curve, this means a mistake in distance of only 2×9000000 mm. = 18 Kilometers or c. 10 miles. I have therefore found it superfluous to employ working-charts of greater size, as this uncertainty in the determination is far less than that originating from the curves' deviation from the real drift course. The distances have only for a few bottles: No. 44, 48, 60, been measured on a chart where 1° lat. is c. 9 cm. The measured length of the curve in cm. gives, multiplied by 90, the distance in Kilometers, and this is by means of the scale on the chart transformed into miles, which corresponds to 1 mile = 1·852 Kilometers. Moreover the table offers information with regard to the number of days passed from the throwing out of the bottle till its recovery (both days exclusive) also the distance in miles divided by the number of days, which gives the average value of the daily drift, or by the formerly mentioned restriction a lower limit for the average value of the current speed of the covered distance. I hope it may not cause the reader any trouble that the speed is stated in miles per 24 hours, as is generally the case in the literature at hand. I shall state, however, in order to facilitate the conversion into cm. per second, that 1 mile per 24 hours = 2·14 cm. per second.

It will be seen from the table that of the 80 bottles thrown out, 49 or about 61 % were recovered (up to January 1st 1908). That the percentage is so high is probably, as mentioned before, owing to the special construction of the bottles, though the circumstance that a reward was promised for the sending in of the label may not have been quite without influence. Besides the already mentioned Danish bottles, of which 29 % were recovered, I shall for the sake of comparison call attention to the fact that only 15 % were recovered of 3553 Scotch current-bottles, the main part of which was thrown out into the North Sea. The treatise at hand [1]), however, is probably printed at so early a time that allowance should be made for

[1]) T. Wemyss Fulton l. c.

No. of bottle	Bottle thrown out			Particulars of recovery				Distance	Number of	Average speed
	Date	N. Lat.	W. Long.	Date	N. Lat.	Long.	Locality	miles	days	miles a day
	1905									
3	18/5	64°24′	8°30′	30/9 1906	69°10′	15°40′ E.	Börvaag, W.-side of Andöen, Norway	692	499	1·4
4				11/4 —	68°00′	13°00′ -	Refsvik, Maaskenæsö, Lofoten, Norway	605	327	1·9
8	19/5	63°40′	10°38′	22/12 1905	63°43′	8°35′ -	Tuvnæs, Fröiens N. W.-side, Norway	550	216	2·5
12	19/5	63°10′	11°45′	5/5 1907	70°50′	26°40′ -	Henrikholmen, Govik, Laxefjord, Norway	1070	715	1·5
15				7/1 1906	67°30′	14°35′ -	Karlsö, Kjerringö, Norway	775	232	3·3
16				30/5 —	65°20′	12°10′ -	Selfjord, Bindalen, Nordland, Norway	680	375	1·8
18				22/10 —	68°17′	15°15′ -	Storselsö, Lofoten, Norway	790	520	1·5
21	19/5	63°43′	11°45′	23/12 1905	70°40′	27°00′ -	Laxefjord, Finmarken, Norway	1090	217	5·0
22				9/4 1906	67°35′	14°50′ -	Leinæsfjord, 25 miles N. of Bodö, Norway	763	324	2·4
24				19/4 —	70°35′	22°10′ -	Brevikbotten, Finmarken, Norway	990	334	3·0
25				14/1 —	70°30′	22°30′ -	Grundfjord, Norway	1005	239	4·2
26				31/1 —	70°25′	28°30′ -	Tanahorn, Finmarken, Norway	1150	256	4·5
27				3/9 —	70°30′	23°00′ -	Gyfjord in Sörösund, Norway	1015	471	2·2
30				27/10 1905	62°30′	6°10′ -	Rösvik, Roald per Aalesund, Norway	513	160	3·2
31	19/5	64°12′	11°45′	23/12 —	67°00′	14°00′ -	Fleinö, 15 miles S of Bodö, Norway	728	217	3·4
33				21/5 1906	69°40′	18°00′ -	Brensholm, Hillesö, Norway	875	366	2·4
36				19/2 —	66°00′	12°30′ -	Tittenæs, Dönnæs, Helgeland, Norway	692	275	2·5
37	20/5	64°58′	11°45′	13/1 —	63°45′	8°40′ -	Vassösund, Fröien, Norway	576	237	2·4
41	25/5	63°36′	16°29′	1/2 —	65°38′	12°00′ -	Dybingen at Röröen, Helgeland, Norway	800	251	3·2
42				23/11 1905	64°45′	11°22′ -	Klingset per Abelvær, Namdalen, Norway	775	181	4·3
44	25/5	63°33′	16°28′	2/7 —	63°52′	21°45′ W.	Herdisarvik, Arnessyslu, Iceland	152	37	4·1
45				4/1 1906	67°12′	14°30′ E.	Strömmen in Bodin, Norway	875	223	3·9
46	25/5	63°30′	16°26′	8/5 —	69°02′	15°30′ -	Bö, Westeraalen, Norway	930	347	2·7
47				29/7 1907	70°28′	30°40′ -	Syltevik, Östfinmarken, Norway	1325	794	1·7
48	25/5	63°27′	16°24′	3/12 1905	63°34′	20°15′ W.	Rangarsand, N. of Vestmanö, Iceland	110	191	0·6
49				2/12 —	60°05′	1°20′ -	Band of Meal, Burra Isle, Shetland	480	190	2·5
51	26/5	63°21′	16°22′	10/4 1907	69°35′	32°20′ E.	Motkafjord, Murmancoast, Russia	1435	683	2·1
52				13/4 1906	70°07′	19°30′ -	Northern Grundfjord, Helgö, Norway	1043	321	3·2
53	26/5	63°16′	16°18′	27/1 —	64°40′	11°08′ -	Sandvig, Fosnes, Norway	775	245	3·2
56	26/5	63°11′	16°15′	10/7 —	70°04′	29°20′ -	Lönsklubben, Varangerfjord, Norway	1395	410	3·4
58	26/5	63°07′	16°12′	25/11 —	64°56′	11°35′ -	Nordeitran, Fjölviken, Namdalen, Norway	785	548	1·4
60	27/5	62°55′	15°38′	15/7 1905	63°29′	18°00′ W.	Ásafjara, 8 miles E. of Kudafljot, Skaftafellssyslu, Iceland	85	48	1·8
62	27/5	62°43′	15°04′	16/1 1906	68°09′	13°54′ E.	Myklevik, West-Vaagö, Lofoten, Norway	865	233	3·7
63	27/5	62°30′	14°30′	22/2 —	63°24′	7°50′ -	Bratvær, Christianssund, Norway	630	270	2·3
64				20/6 —	63°45′	8°35′ -	Nordyrö, Fröien, Norway	660	388	1·7
65	27/5	62°15′	13°48′	14/10 1905	63°01′	7°15′ -	Langö at Kvitholmen Light, Christianssund, Norway	600	139	4·3
66				19/10 —	62°45′	6°50′ -	Björnsund, Romsdalsfjord, Norway	575	144	4·0
67	27/5	62°07′	13°05′	10/1 1906	65°48′	12°00′ -	Kilvær, Helgeland, Norway	753	227	3·3
68				14/11 1905	60°47′	0°48′ W.	Scaw, Haroldswick, Unst, Shetland	382	170	2·2
69	28/5	61°59′	12°22′	12/12 —	c.61°10′	c.5°00′ E.	c. 50 miles N. of Bergen, Norway	524	197	2·7
86	28/5	61°50′	11°38′	28/1 1906	66°48′	13°25′ -	Melövær, Helgeland, Norway	775	244	3·2
87				29/6 1905	61°50′	6°40′ W.	Skaalevig, Thorshavn, Faroe Islands	144	31	4·6
88	28/5	61°11′	11°00′	17/9 —	63°10′	8°00′ E.	Tusteren, Christianssund, Norway	582	111	5·2
92	28/8	62°36′	12°05′	22/12 —	63°25′	7°50′ -	Smölen, Christianssund, Norway	557	115	4·9
93				11/12 —	62°10′	7°00′ W.	Leinum, Strömö, Faroe Islands	150	104	1·4
94				17/12 —	64°48′	10°57′ E.	Skjærvær, Vigten, Namdalen, Norway	655	110	6·0
96				6/1 1906	66°38′	13°03′ -	Rödö, Helgeland, Norway	733	130	5·6
97				1/1 —	64°08′	10°10′ -	Wæreth, Björnör, Roan, Norway	625	125	5·0
98				30/1 —	67°00′	14°00′ -	Fleinö, Helgeland, Norway	770	154	5·0

the possibility that more bottles may still be recovered (treatise printed 1897, bottles thrown out from 1894 till February 1897).

Of the recovered 49 bottles 3 landed on Iceland, 2 on the Faroe Isles, 2 on the Shetland Isles, 41 in Norway, and 1 in Russia. This means that only 3 were found west of the place where they had been thrown out, while 46 were found east of that place. As will be seen from the table and chart the bulk of the bottles thrown out divide — a few in August excepted (No. 91—98) — into two different groups. The first consists of those thrown out from the hydrographical seasonal stations (situated across the Faroe—Iceland ridge), in total 37, of which 30 were thrown out at 11° 45′ W. Long. from 63° 10′ to 64° 58′ N. Lat. The other group of bottles from the south-east coast of Iceland in the direction of North Scotland comprised 35 bottles. The first of these were thrown out at a distance of ca. 14 miles from Iceland's coast (about south of Ingolfshöfdi), generally 2 in the same place and for the first couples with intervals of 3—4 miles. Thus the first 18 bottles were distributed on a line of a length of about 30 miles, while the intervals for the rest became somewhat increased, which will be seen from the table and the chart.

All the bottles of the last group were thrown out into warm Atlantic water of temp. 7°6—8°6 C. This was also the case with the greater part of those thrown out from the fixed hydrographical stations, except No. 37—40, which were thrown out into rather unmixed Arctic water of temp. 1° 50, and No. 2—4, which were thrown out into the narrow belt of mixed water on the border of the East-Icelandic polar current, temp. 4°50. Of the second group's 35 bottles, 25 have been recovered (Iceland: 3, Shetland: 2, Faroe Isles: 1, Norway: 18 and Russia: 1). But it is hardly an accident that the number of recovered bottles only amounts to 18 for the first group comprising 37 bottles, as some of them have probably remained in or passed into the East-Icelandic polar current and taken part in the rotating movement of this, without coming in contact with a coast. Having performed a circulation in the Norwegian Sea they may probably drift ashore at North Iceland or at the northern part of the west coast of Norway. As might be expected, all the recovered 18 bottles drifted towards east following the Atlantic current and landed on the coast of Norway. In addition to these two separate groups of bottles, both thrown out in May of 1905, 8 bottles were thrown out at the end of August at 12° 05′ W. Long., 62° 36′ N. Lat., and of these 6 were recovered (Faroes: 1, Norway: 5).

Of least interest are the bottles of the first group. We have no reason to doubt that they have all moved into eastern direction north of the Faroe Islands, and the 18 recovered bottles are, as mentioned before, all landed in Norway. The average speed is on the whole slight, the greatest amounts to 5·0 miles per 24 hours, and it is strange to say one of these bottles which have travelled the greatest distance, as it was found in Laxefjord in the East Finmarken, having passed over a distance of ca. 1100 miles in about 7 months. After this come two bottles with a speed of respectively 4·5 and 4·2 miles per 24 hours, also from the north coast of Norway, the distances being 1150 and 1005 miles respectively. As the quickest bottles are to be found among those that have passed over the greatest distances, there is no reason to fear that the calculated average speed should be greater than the normal, what might occur when the bottle had only been drifting for a shorter distance, where it might have been influenced by winds, that might have quickened its movement. The obtained average speeds are even for these too small to offer any basis for a supposition of this kind. Besides these 3 bottles there are only 4 whose average speed is beyond 3 miles per 24 hours, 6 bottles are between 2 and 3 miles, and 5 of less than 2 miles per 24 hours.

It is possible that the fact that the quickest bottles are among those which landed in the northernmost of Norway might be ascribed to the circumstance that the current rapidity was slight in the area where the bottle was thrown out, while its speed became increased when approaching the coast of Norway, so that the bottles which had drifted for a long distance along this coast thus obtained an

increase in their average speed in proportion to those which drifted along the shore only for a shorter distance, but as we have to deal with so many factors here, for instance for how long they had remained ashore before they were found, an investigation of this kind will always be rather uncertain, and it is quite out of the question on the basis of the material at hand to draw such conclusions, as it is too insufficient in that respect. A view of the table seems on the contrary to show with some certainty that the bottles of this group have on an average landed more northerly than those of the other group. This is also probable, as these bottles for the main part were thrown out very near to the border of the East-Icelandic polar current (which on the meridian of the Faroe Islands generally is found at about 63½° N. Lat.), and consequently during the east-going movement have passed the Faroe Islands' meridian more northerly than the bottles of the other group, which involves that when the waters a little further east take a more northerly course these bottles are separated from the coast of Norway by a greater distance than these latter ones and consequently must be carried further north by the current before getting in contact with the coast. According to Professor HENSEN's before mentioned experiment we must of course be prepared for exceptions, and as a very striking one bottle No. 37 may be mentioned. It was thrown out in the Arctic current at ca. 65° N. Lat. and landed in Norway at 63° 45′ N. Lat. thus about 75 miles further south than it was thrown out.

The bottles of the second group (from Ingolfshöfdi towards S. E.) differ from those in the first group both with respect to the number of the recovered bottles and in the regularity of the distribution of these. It has already been mentioned that of 35 bottles 25 were recovered, the main part, 18, in Norway, 1 in Russia, 2 on the Shetland Islands, 1 on the Faroe Islands and 3 on Iceland. According to Captain RYDER's current chart in the paper above mentioned it might be expected that nearly all these bottles — for the rest also the greater part of those of the first group — would be carried towards the S. E. coast of Iceland and then around the island from S. to W., N. and the East coast, after which those not stranded on the way should continue towards the coast of Norway. The question is now if the distribution of the recovered bottles is in accordance with this theory.

I beg here to remark that in a discussion of the hydrographical conditions at the Faroe—Iceland ridge in 1903[1]) I arrived at the conclusion that the waters here must move into easterly direction, and when the number of bottles thrown out at 11° 45′ W. Long. was so great, it was because I wanted with certainty to get settled the course of the waters in this section, also for the surface layer. When the movement, however, from 11° 45′ W. Long. and further eastward to the Faroes is towards east, the division of the Atlantic current drawn up by Captain RYDER must be more southerly, and a movement of the western branch into north-western and western direction towards the coast of Iceland becomes highly improbable, and I supposed that this series of bottles from Ingolfshöfdi till about 11° W. Long. would be sufficient to show where this division took place, if it on the whole occurred, what there seemed to be reason to doubt.

Of the 3 bottles which were found on Iceland the two were thrown out at about 16½° W. Long. at a distance of respectively 14 and 17 miles from the coast, while the most eastern of them (No. 60) was thrown out at 15° 38′ W. Long. in ca. 60 miles' distance from the shore. The speed is for the two latter very inconsiderable, respectively of 0·6 and 1·8, but as both were found on the almost uninhabited stretches on the south coast the speed of drifting may possibly be far greater, and the low values may be due to the circumstance that the bottles were not found till some time after their drifting ashore. The first bottle gives on the contrary a rapidity of 4·1 miles per 24 hours, but it has probably also been found shortly after its landing, as the finding place belongs to the thickest populated parts of the coast, and still we cannot call this speed particularly great, as Captain RYDER indicates the current speed at the south coast to amount to 6—7 miles per 24 hours.

[1]) Meddelelser fra Komm. for Havundersögelser. Serie: Hydrografi. Bind I. No. 4.

As not a single one of the bottles thrown out further east was found at Iceland we should — if we from these bottles were to judge where this supposed division of the Atlantic current takes place —, have no reason to suppose that this division takes place east of the 15° meridian. To this we might object that this division excists as indicated on Ryder's chart and that the bottles had floated around Iceland without drifting ashore. Now it is, in the first instance, incredible, however, that let us say at least 30 bottles should have drifted around almost the whole extensive coast of Iceland, the length of which is about 800 miles (the Fiords and Bays excepted) or of about the same length as the coast of Norway from Christianssund to Vardö, the stretch where the current-bottles mainly were found, and only 3 bottles should have remained on the coast. Even if we would suppose that some of the 10 bottles, which were not found, should be laying somewhere on the coast of Iceland, we obtain in most 13 bottles on Iceland, while we with certainty know that at least the 22 bottles found in Norway, the Faroe Islands and the Shetland Islands have gone clear of Iceland. The last figure remains therefore too large in proportion to the number of the bottles, which during the long drifting along the coast may possibly have remained ashore. Secondly, the distance covered by the bottles will be very considerably increased by such a detour around Iceland and the values of the average speed or the daily drifting will for some of the bottles approach the absurd. If we regard for instance bottle No. 42 (found in Namdalen in Norway), being one of those thrown out at the shortest distance from Iceland, wherefore the increase in distance would be least, the average speed for this would be 8·5 miles per 24 hours, if we suppose a drifting around Iceland, while it when drifting in eastern direction would be 4·3 miles a day, as stated in the table. The further east the bottles were thrown out, the greater becomes the distance which must be added, if we suppose the bottles to have drifted at first in western instead of in eastern direction, and I shall as an example mention the bottles No. 65, 66, 68, 69 and 87 which would have obtained the following speed instead of that stated parenthetically after each number:

No. 65: 10·0 (4·3), No. 66: 9·6 (4·0), No. 68: 7·4 (2·2), No. 69: 7·4 (2·7), No. 87: 35·2 (4·6).

Moreover, the bottles thrown out in August at ca. 12° W. Long. which we later on shall mention, will all have a speed varying from 10 to more than 13 miles per 24 hours instead of 1·4—6·0 miles.

Even if a bottle very well may drift with a speed of 10 miles per 24 hours in this particular area, if the question is about a shorter period, for instance of some days, there is nothing which suggests that such a high value may be obtained when the question is about the average speed of a period of several months, as the case is here. For the two stated reasons it will be natural to suppose that the main part of the bottles in question have taken an eastern direction towards the Faroe Islands, and that only a lesser or inconsiderable part of them have moved in N. W. or W. towards the coast of Iceland.

Thus we feel obliged to abandon the usual view as represented by Captain Ryder: A division of the current at 10—11° W. Long. and a movement of the western part in N. W.-ly and W.-ly direction towards the coast of Iceland, and we have the more reason to do so as a critical survey of Captain Ryder's chart and tables give in many cases just the result that there is much more probability for the opposite course than for the adopted one. As an example I shall mention the bottle "Godthaab" No. 4′ and "Diana" No. 7′ which, according to Captain Ryder, move from the S. E. coast of Iceland around Iceland and to Norway with a speed of respectively 9·2 and 9·8 miles a day. These somewhat improbable values become considerably reduced (about half) and in better accordance with the rest if we suppose that they have at once moved into eastern direction.

Of the 8 bottles, which at the end of August were thrown out at 62° 36′ N. Lat., 12° 05′ W. Long., 6 were found, one of them at the Faroe Islands and 5 in Norway. The average speed of the first is only 1·4, and it has probably been laying ashore for some time, or it may possibly have drifted about in the

sounds between the islands without getting clear of these. The rest were found on the coast of Norway from ca. 63½—67° N. Lat. They show all a high average speed, from 4·9—6·0 miles per 24 hours, which means that they have on an average moved with greater speed than the formerly mentioned, and that 2 of them at any rate show higher speed than any of these, namely 5·6 and 6·0 miles per 24 hours. Already on account of this proportionately high value of the average speed, which is in good accordance with earlier statements, it would be absurd to suppose that they in spite of being thrown out west of the current division indicated by RYDER should have moved around Iceland, and when we to this add the fact that none of the bottles were found on this island and that the average speed in that case would be from 10 to at least 13 miles per 24 hours, it is evident that the bottles must immediately have taken an eastern course. We notice moreover that all these 6 bottles landed about the same time, namely in December and January, and though the bottles which were thrown out in May might be supposed to reach the coast of Norway several months before these — this may for the rest be seen from No. 88 which landed at Christianssund in September — it is first in the 2 stated months that a greater number of them was found, namely 9 and 12 respectively, while only 9 in total were found from June till December 1st. This circumstance is probably connected with the occurrence of the belt of coast-water i. e. fresher water — and also partly warmer in summer — and consequently lighter, which may be found at the coasts and to an especially high degree at the Norwegian coast, originating from rain-fall and melting of ice in the mountains and also from the continuation of the Baltic current. The coast-water will on account of its lower specific gravity and from this arising difference in the hydrostatical pressure endeavour to move away from the coast perpendicularly to this, and it will consequently when this movement is strongest partly be able to prevent the objects drifting in the surface from reaching the coasts. In winter, when the rain-fall over the country is partly transformed into snow and ice, the difference in salinity becomes slighter, and the lower temperature over the country will moreover by cooling of the waters nearest to the coast take the effect of equalizing the difference in specific gravity and in pressure, wherefore the movement of the shore-water in direction away from the coast will become feebler or perhaps quite cease. Through a strong cooling of the water near the coast and through scarce supply of fresh water it may perhaps even obtain higher specific gravity than the surface water in the sea outside, and in this way a surface current towards the coast may arise. It will then be seen that we in winter with far greater probability may expect an object drifting in the surface of the sea to move through the coast water belt and to reach the shore.

When forced by the circumstance that only 3 of the landed bottles were found at Iceland and only a slight number of the rest — if any — have moved in western direction south of Iceland we feel obliged to suppose that the main part of the thrown out bottles have moved in easterly direction, we must consequently say that the current direction in the sea east of Ingolfshöfdi's meridian has a composant in easterly direction. In this case it will be natural to suppose it in the main features to be parallel with the border line between the warm Atlantic water and the East-Icelandic polar current, as this border, though object to certain irregular shiftings, is found on the whole at about the same place and is particularly very sharp, which shows that the direction of the current on both sides of this border line, at any rate in the neighbourhood of this, must be parallel with it. The question is now how the 3 bottles found at Iceland may have been able to move into western direction, consequently against the current. I want in this connection to call notice to the fact that a current in the sea should not be understood as a continual movement of the waters, but that these may be subjected to all possible movements from which the resulting movement originates, also that completely identical bodies in drifting may separate considerably from each other (compare Professor HENSEN's experiment p. 6). I suppose that these bottles by such irregular oscillations of the waters have got near the coast of Iceland and thus have entered the so-called

Icelandic coast current and by this been transported in western direction along the south coast. (The two of them were thrown out at a quite inconsiderable distance from this.)

With regard to this coast current I want to make a few remarks as it is generally represented as a continued current circuit around the entire coast of Iceland. This is only partly right. If we go from the south- to the west- and north-coast together with the northern part of the east-coast, we find the characteristic features of such a continual circuit, small and gradual variations in the temperature and salinity, but in the neighbourhood of Vestre Horn (64° 15′ N. Lat., 14° 50′ W. Long.) we meet with a sudden rise in temperature and salinity, which especially regarding the temperature is very conspicuous, as this on a stretch of a few miles generally changes ca. 5° C. This proves that the cold waters from the East-Icelandic polar current must leave the the coast at this place. If this was not the case, but that an outlet of it continued along the S. E.-coast, it would still for some distance preserve its Arctic character and only gradually by mixture with the warm Atlantic water outside pass over in this. That would, however, involve a gradual increase in temperature and salinity, and this has as far as I know never yet been observed, while I myself about a dozen of times in the years 1903—1905 have been able to substantiate this sudden change in temperature in the neigbourhood of Vestre Horn. Moreover it seems to me that this sharp limit furnishes a proof that the warm Atlantic water at the S. E.-coast must move in N. E.-direction parallel with the coast. If we should imagine the course of this to be the opposite, we might just expect the Arctic water coming from the North along the coast to continue its movement along the coast inside the warm water, and thus through successive mixture with this show even transitions in temperature in the direction of the movement, also parallel with the coast, while the temperature of the waters would increase rapidly coming outside this coast current; this, however, can not be pointed out either.

As the Arctic water does not continue its course along the coast south of Vestre Horn a break in this coast current is thus found here, and provided that such an anticyclonic movement along the S. E.-coast really exists, it must probably be limited to a very narrow belt along the shore and ought rather to be considered as a kind of eddy-water. At some or other point of the south coast, probably between the Vestman Isles and Ingolfshöfdi, a division of the Atlantic waters appears to take place[1]), so that the western part moves into western direction and northwards into the Denmark's Strait having passed the Cape Reykjanæs.

Thus we arrive at the conclusion that from a point at the south coast, off the Vestman Isles or a little more eastward, a continual current is running in the same direction as the hand on a watch till Vestre Horn, but as the current direction in the sea outside is the same (a short stretch off the north-west coast excepted), and as the waters nearest to the coast do not essentially differ physically and chemically from the surrounding ones, short of the small changes which the waters at any shore are always subjected to, it is so far wrong that a particular Icelandic coast current has been set up, and especially as we have seen that the waters of which it consisted at the northern part of the east coast completely leave the shore at Vestre Horn. South of this place no particular coast current seems to exist, and, if found, it may hardly be supposed to assume an independant character but rather appear as a kind of eddy-water. I may in connection with this mention that Admiral Wandel[2]) by a discussion of observations made from the mail-steamers at the south coast of Iceland also arrived at the result, that none of these observations contained any support of the supposition of such a coast current, but nevertheless he writes

[1]) In support of this supposition may serve that of the great amount of cod-fry, which is found in spring on the banks at Iceland's south coast, mainly from the Vestman Isles to Reykjanæs, the bulk drift northwards along the west coast of Iceland, while we find only proportionately few of them later in the year at the S. E. coast. Comp. Johs. Schmidt: Fiskeriundersögelser ved Færöerne og Island i Sommeren 1903. Skrifter udg. af Komm. f. Havundersögelser. Köbenhavn 1904.

[2]) C. F. Wandel og C. Ostenfeld: Iagttagelser over Overfladevandets Temperatur, Saltholdighed og Plankton paa islandske og grönlandske Skibsrouter i 1897. Köbenhavn 1898.

as follows (p. 11): "That such a current does exist along the mentioned coasts may not be denied though it does not appear from the measurements. The current exists without doubt and is maintained by Arctic water coming round Cape Langanes inside the East-Icelandic polar current, from the ice-waters of the numerous rivers". The reason why such a coast current has been represented on this stretch may probably chiefly be due to the circumstance that drift-ice has sometimes occurred at the south-coast of Iceland, but it is very rare that the ice comes down to that part of the coast, which normally is watered by warm water (south of Vestre Horn), and when it happens, indeed, the reason must surely be ascribed to strong and continual northern and eastern gales, which push the ice southward along the coast and prevent it from leaving this again.

The speed of the waters between Iceland and the Faroe Isles may naturally not be deduced from the material at hand, as only 2 bottles were found on the Faroe Isles, and these 2 had been thrown out at a distance of only 150 miles. One of these showed an average drift of 4·6 miles per 24 hours, the other of only 1·4. The distance being so short we do not obtain any information regarding the western part of the area nearest to Iceland. Of the hydrographical changes, which in the years 1903—1905 have taken place between the seasonal investigations in May and in August, it becomes evident, however, that the current speed is on an average very low, but any absolute value may not be deduced from these measurements, as the condition further south in the Atlantic, wherefrom the replacing waters come, was not subjected to a closer investigation. If, however, the current speed off the S. E.-coast of Iceland is only slight, it is easy to explain the occurrence of such irregularities that some bottles may adopt a course opposite of others, as local rotations, which probably are far more frequent than generally supposed [1]), obtain far greater influence when the translatory movement takes place slowly.

Captain Ryder states in his paper mentioned before that the current speed between Iceland and the Faroe Islands is about 4 miles per 24 hours, but he assumes, however, quite wrongly that a current-bottle may only be carried into this direction by the East-Icelandic polar current, while in reality a great part of the bottles mentioned under the section: the East-Icelandic polar current, must be carried off by the warm Atlantic water. It appears that Captain Ryder has in a too high degree neglected exact measurements and has drawn too far-reaching conclusions from the drift of the bottles. Thus he arrives at the following peculiar result (p. XX): "The current (ɔ: the East-Icelandic polar current) passes both north and south of the islands (ɔ: the Faroes) and takes hereafter direction towards the Shetlands meeting on the way a branch of the Gulf-Stream. Together with this latter it turns gradually more and more eastward, passes north of the Shetlands and continues in N. E.-ly direction up towards the coast of Norway". With regard to this it should be remarked that the limit between the Arctic current and the warmer water on the meridian of the Faroes were found at about 63½° N. Lat. (always between 63° and 64°) by the regular measurements of later years, and that the daily observations of temperature in Thorshavn in the years, for which I have had material at hand (1890—1905), never give any reason for the supposition that the Faroe Islands are surrounded by Arctic water, which especially in winter is very easy to point out, the surface temperature being below 1° C. in the true East-Icelandic polar current during this season. Moreover it is a well-known fact that between the Faroe Islands and the Shetlands we find generally the warmest and most saline water, which on the whole occurs on this parallel, and absolutely not waters of Arctic origin. [2]) The author continues p. XXI: ". . . . . This shows that the current strikes the Norwegian coast on about Lat. 63° off Christianssund from where it moves further north along the coast". It is truly a most astonishing result that the East-Icelandic polar current should flow northwards along the coast of Norway, as it is a well-known fact that off the entire west-coast of Norway we find a belt of warm Atlantic water of a salinity beyond 35 ‰, and which consequently may not have been subjected to any noticeable influence of Arctic water. The limit between the warm water and the

[1]) Comp. B. Helland-Hansen: Ozeanographie des Nordmeeres. Publication de Circonstance No. 19. Köbenhavn 1904.
[2]) Comp. f. inst. C. F. Wandel and C. Ostenfeld l. c. p. 10.

Arctic current will for instance appear from the surface chart in "Bulletin des résultats" for May 1903 [1]), for which year the chart is most complete concerning this area, as the 35 ‰ isohaline, and the 5° isotherm, which is almost joining this, may almost be considered as a border line. Even if this isohaline in May, 1903 may perhaps have been situated somewhat more westerly than is normally the case, an extension of the East-Icelandic polar current till east of Greenwich's meridian south of the 65th parallel has, as far as I know, never been observed.

That the great number of bottles, which according to Ryder's opinion have been taken to Norway by the East-Icelandic polar current, may not on the whole stretch have been carried off by this, does in no way complicate the matter. In the first instance a great part of the bottles have after all not occurred in this current, and those which really were thrown out in this current or carried into it have later on passed over into the Atlantic water, where the two currents move parallel with each other, either north of the Faroe-Iceland ridge or further eastward, where the East-Icelandic polar current bends into northern direction, and the further drifting of the bottles have thus taken place in the Atlantic water.

How are we now to explain the opposite views concerning the currents of the water between Iceland and the Faroe Islands? I beg here in the first instance to call attention to the fact that the material worked out by Captain Ryder shows great discrepancy, which for instance appears very plainly on the charts No. III and IV ("Tejo" October—November 1899 and "Ceres" May 1900). As the bottles from the "Tejo" represent the current system set forth by me, while those from the "Ceres" illustrate the opposite view [2]) it will thus become quite individual to which of them we attribute the greatest value. When moreover — what we have reason to suppose — the current speed is low in this area, it may easily be explained why proportionately slight causes may lead to deviations from the normal features. Continual easterly winds may surely cause a movement towards west in the entire surface layer, just as the irregularities in the surrounding currents, for instance great supply of water through the East-Icelandic polar current may be able to rise a retrograde movement in the waters between the Faroe Islands and Iceland. After all we may surely with good reason remark that the information concerning currents in the sea which may be provided by means of current-bottles is much inferior to the results, that may be obtained through exact and carefull observations of the distribution of temperature and salinity in certain suitable sections and through the study of the changes taking place in these from time to time. The employment of current-bottles has the advantage of not demanding so great an apparatus as the latter investigations, but in return the current-bottles furnish information only with respect to the movement of the surface water and may, as shown above, not without reservations provide us with information regarding a certain current, if the domain of this has not been settled in advance through physical and chemical investigations.

The safest method for the investigation of the currents in the sea will naturally be exact current measurements, and the current-meter constructed by Dr. Ekman [3]) in Christiania, which Mr. Helland-Hansen [4]) after extensive experiments has found to be excellent, also for measurements on deeper water, will probably be much used in future. The value of such investigations will, however, highly depend on our success in providing so great a material that the tide and other irregularities may be eliminated, so that the average value of the current speed from different parts of the sea can be deduced from the observations.

[1]) Comp. moreover the surface chart for May in Medd. fra Komm. f. Havundersögelser. No. 4.

[2]) It appears from the Meteorological Annual 1900 II that easterly winds south of Iceland were predominating during May, June and July 1900 and a few times took the character of gales (the observations from Vestmanö).

[3]) V. W. Ekman: Kurze Beschreibung eines Propell-Strommessers. Publications de Circonstance No. 24.

[4]) B. Helland-Hansen: Current-measurements in 1906 p. 4. Bergens Museums Aarbog 1907. No. 15.

550. 3/v 1908.

Chart showing the drift of the current-bottles.

Medd. fra Komm. for Havunders. Serie: Hydrografi. Bd. I. Nr. 11.